THE TEMPERATURE COEFFICIENT OF THE DURATION
OF LIFE OF CERAMIUM TENUISSIMUM

Arthur H. Ayres

Reaction velocities at various temperatures have become of much interest to biologists, on account of the possibility they present for the identification of certain physiological processes as chemical or physical, since it has been found that certain common physical and chemical reactions have rather characteristic temperature coefficients. Thus, if we suspect that a certain reaction is due to a chemical process, we can determine whether or not the velocity of the reaction at various temperatures is of the magnitude demanded by a chemical reaction. Since the temperature coefficients for all chemical reactions do not always have the same order of magnitude as demanded by the van't Hoff rule on the dependence of the rate of reaction of chemical processes upon temperature (9), the test is not wholly conclusive, but indicates rather a probable explanation of the phenomenon in question.

Animal physiologists in recent years have given much attention to temperature coefficients, but very little work has been done upon this subject by plant physiologists. Clausen (2) was the first to show that the rate of evolution of carbon dioxide from seedlings and buds was about doubled with an increase of 10° C. Miss Matthaei (5) found that van't Hoff's rule applied to the fixation of carbon dioxide by leaves in sunlight and to the evolution of this gas by leaves in the dark. Price (7) determined the temperature coefficient for the opening of flower buds, and found it to have the magnitude demanded for a chemical reaction.

It will be seen that these experiments deal with growth phenomena. Loeb (4) was the first to call attention to the fact that the temperature coefficient of the duration of life of sea urchin eggs differs widely from that of their development, the temperature coefficient of development being 2.86 for a rise in temperature of 10° C., while that of duration of life is nearly 2 for a rise in temperature of 1° C. Moore (6) found that the temperature

coefficient of the duration of life of *Tubularia crocea* stems was of the same order of magnitude as that found by LOEB for sea urchin eggs, being about 2 for each degree centigrade rise in temperature. The results of these investigations on animals led GOODSPEED (3) to determine the temperature coefficient of the duration of life in barley, which was found to be 1.27 for an interval of 1° C., or about 11 for 10° C. This result is much lower than that found by LOEB for sea urchin eggs, and by MOORE for hydroid stems, and is much higher than the temperature coefficients determined for growth phenomena in plants.

The results obtained with barley involved the use of relatively high temperatures, and it was suggested to me that similar investigations upon the marine algae, involving a lower range of temperature, might yield data which could more properly be compared with the results obtained with simple animal organisms by LOEB, MOORE, and others. Another reason for using an alga is that we then deal with a much simpler structure than was used by GOODSPEED (*loc. cit.*), thus eliminating to a certain extent the possibility of unknown factors entering into the experiment.

Physiologists have recognized that the degree to which van't Hoff's rule applies to physiological processes is determined by the degree of uniformity in which experimental material is affected by the environmental changes. Thus, whenever it is possible, isolated cells are chosen for experimental purposes, a small energy change being the most influential cause of uniformity in physiological reactions (cf. BARRY 1). In this connection it is to be noticed that the tissues used for observation in the present experiment were those in the apical region, and were thus embryonic in character; hence, the following observations are more nearly comparable with those of other investigators who have used embryonic animal cells or tissue in their investigations.

Of the material available, certain members of the Rhodophyceae were chosen, especially those species which are known to show a more or less definite death point by a rapid and distinct change of color. In a number of preliminary experiments the plant which passes commonly as the Pacific Coast form of *Ceramium tenuissimum* gave the sharpest death point color reaction, and for this reason was used exclusively.

The material was collected from floats in a tidal estuary of San Francisco Bay. The temperature of the water in which *Ceramium tenuissimum* occurs undoubtedly varies somewhat with the change of seasons, but during the winter the temperature is practically constant at 9–10° C. The plants to be brought into the laboratory were placed in jars of sea water at the place of collection. In the laboratory they were kept at a temperature of 12–14° C. by immersing the jars in a stream of running tap water. By replacing the sea water occasionally the material was kept growing normally in the laboratory for several days.

Two methods were employed for obtaining and maintaining the desired temperatures. In the first place, the temperatures were kept constant within an asbestos-lined hood by means of a double water bath heated by a Bunsen burner, which was automatically regulated by a mercury thermo-regulator. By placing covered finger bowls containing sea water on shelves in the hood above or around the water bath, a considerable number of constant temperatures was obtained. The second method consisted in placing a double bell jar filled with water over a heavy glass dish containing the material in sea water. This apparatus was then placed on top of a glass case which inclosed a 16-candle-power incandescent light. A free circulation of air maintained the temperatures constant to ±0.5°. The various temperatures desired were obtained by shifting the position of the bell jar and the dish with reference to the light. The results secured by these two methods of obtaining constant temperatures agreed so closely that both were employed.

A finger bowl, containing 100 cc. of sea water, covered to prevent evaporation, was brought to the desired temperature and maintained constant there for about 30 minutes; a number of plants were then transferred directly from the aquarium to the finger bowl. At intervals some of the material was removed from the finger bowl and transferred to a small quantity of sea water at the temperature of the laboratory. "Duration of life," as used in table I, was taken as the time for which a given temperature must act to cause a change in color of the apical cells of the branches from maroon, the normal color, to brick red color, which is characteristic of dead material. This change in color is due probably

to a change in the permeability of the chromatophores, thus allow-
ing the phycoerythrin to diffuse out into the cell contents. The
larger cells of the plant show this diffusion of the pigment before
smaller cells at the tip show any such change. The change in color
is most evident after the plant has been left standing at room tem-
perature for 6–10 hours after removal from the constant tempera-
ture chamber. Branches which remained the normal color after
heating were found to proliferate and grow to some length when
allowed to stand, while those which showed diffusion of the coloring
matter from the chromatophores did not grow further. This fact
justifies the use of the color reaction as an indicator of the duration
of life. Table I expresses the average results of a number of
experiments.

TABLE I

Temperature (centigrade)	Duration of life (minutes)	Mean temperature coefficient for 1° C.
28...............	300–340	320
		.....1.21
29...............	240–285	262.5
		.....1.12
30...............	210–255	232.5
		.....1.16
31...............	185–215	200
		.....1.15
32...............	160–185	172.5
		.....2.15
33...............	75– 85	80
		.....1.18
34...............	60– 75	67.5
		.....1.42
35...............	40– 55	47.5
		.....1.58
36...............	25– 35	30
		.....2.14
37...............	12– 16	14
		.....1.64
38...............	7– 10	8.5

Average temperature coefficient for 1° C., 1.47.

The temperature coefficient of the duration of life of *Ceramium
tenuissimum* has been determined thus for the temperatures
28–38° C. inclusive, and found to average 1.47 for each degree
centigrade rise in temperature. This average temperature coeffi-
cient corresponds closely with that found by GOODSPEED (1.27),
whose experiment involved the use of much higher temperatures

for barley grains, but is less than that found by LOEB for sea urchin eggs and by MOORE for hydroid stems.   This result is of far too great a magnitude for any of the well known physical processes, whose temperature coefficients seldom reach a magnitude as great as 2 for a 10° C. interval (cf. SNYDER 8).

Although there is some question as to the value of temperature coefficients as indicating the exact nature of physiological processes, it seems fitting to make this contribution to our knowledge of a subject which may sometime give us a better understanding of fundamental biological phenomena.

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UNIVERSITY OF CALIFORNIA

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